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SENSOR FEASIBILITY REPORT; SURVEY OF THE CAPABILITIES AND LIMITATIONS OF CHEMICAL, BIOLOGICAL, RADIOLOGICAL, NUCLEAR AND EXPLOSIVE (CBRNE) SENSOR TECHNOLOGIES RELEVANT TO VEHICLE INSPECTION SYSTEMS

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Sensor Feasibility Report:

Survey of the Capabilities and Limitations of CBRNE Sensor Technologies Relevant to Vehicle Inspection Systems

FA4819-06-C-0012

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14. ABSTRACT

This report provides a summary of KRD's research on existing Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNE) sensor technologies and possible incorporation into Under Vehicle Inspection Systems (UVIS) platforms, as provided in the sensor integration plan. Sections two through five discuss how KRD could potentially integrate these technologies into its Under-Vehicle Inspection System (UVIS) platforms, thereby enhancing their threat detection capabilities. These sections also focus on the practical implications of each sensor technology, including capabilities, limitation, operational considerations, and integration with UVIS platforms. Detailed information on the theory and principal of operation for each sensor technology can be found in the references. Section six presents a sensor integration plan for incorporating sensor capabilities into KRD's UVIS platforms for large vehicles. This plan summarizes the practical considerations in selecting a CBRNE sensor. Additionally, it discusses the advantage of selecting a "weigh-in-motion" capability as the first sensor technology that KRD will use in conjunction with its UVIS platforms.

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Executive Summary

This report constitutes the two contract deliverables related to sensor integration, which are specified in Contract #FA4819-06-C-0012 to Kachemak Research Development, Inc. (KRD):

- Research Report on Sensor Technologies Relevant to Vehicle Inspection Systems.
- Sensor Integration Plan for Large Vehicle Inspection Systems.

Sections two through five of the report constitute the research report on sensor technologies. These sections present a broad summary of existing Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNE) sensor technologies. Additionally, they discuss how KRD could potentially integrate these technologies into its Under-Vehicle Inspection System (UVIS) platforms, thereby enhancing their threat detection capabilities. Also, these sections focus on the practical implications of each sensor technology, including capabilities, limitations, operational considerations, and integration with UVIS platforms. Detailed information on the theory and principal of operation for each sensor technology can be found in the references.

Section six of the report presents a sensor integration plan for incorporating sensor capabilities into KRD's UVIS platforms for large vehicles. This plan summarizes the practical considerations in selecting a CBRNE sensor. Additionally, it discusses the advantage of selecting a "weigh-in-motion" capability as the first sensor technology that KRD will use in conjunction with its UVIS platforms.

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1. Explosive and Chemical Warfare Substance Detection

Improvised Explosive Devices (IEDs) are the most common terrorist threat today. Many of the sensor technologies used to detect explosive materials (such as those found in IEDs) can also be used to detect chemical nerve agents and biological agents. However, it is important to note that although some sensors are capable of detecting and identifying multiple analytes, they may not be able to do so in one analysis. The chemical differences between explosive compounds and nerve agents are significant. Therefore, most instruments need to be specially calibrated with standards that are specific to the warfare agent of interest. Spectroscopic-based methods (LIBS and Raman) may need extensive spectral reference libraries or specialized sample preparation to insure accurate substance identification. Additionally, environmental and/or sensor detection limitations vary with each substance and may affect sample collection. This requires instrumental or operational adaptations of sampling protocols for field applications. Common chemical agents and explosive substances are listed in Table 1 in the Appendix.

The following subsections provide an overview of the commercially available and emerging sensor technologies (for explosive and chemical warfare substances) that could be potentially integrated into KRD's under-vehicle inspection systems.

1.1. Surface Enhanced Resonance Raman Spectroscopy (SERRS)

Raman Spectroscopy has been used successfully for many years in forensic and medical laboratories to identify explosives, illicit drugs, polymers, proteins, DNA base pair sequences and so forth. It can also detect Chemical Warfare (CW) substances, but only when the sample is contained in a clear glass container through which light can pass [1]. In field applications, chemical agents stored in metal drums at munitions dumps could not be analyzed by Raman Spectroscopy unless the drum was opened and the contents sampled.

Advancements in Raman spectroscopic methods, such as Surface Enhanced Resonance Raman Spectroscopy (SERRS) and the advent of microfluidic Lab-On-A-Chip (LOC) technology, has resulted in the development of instruments that combine these two technologies for the detection of explosives and biological threat agents [2]. These integrated instruments promise to greatly reduce or eliminate the possibility of false positives or negatives. Additionally, they provide an ultra-sensitive (< 1 ppb), fast (1-2 minutes), and portable way to monitor for the presence of explosive and biological threat agents [3]. SERRS-LOC instruments would not require spectral libraries for chemical identification. However, they may require specialized derivitizing reagents to achieve accurate results for explosive identification.

Significant research and development efforts are currently in progress to apply SERRS (in combination with Lab-On-A-Chip technology) to explosives, biohazards, and chemical warfare agent analysis. Although on-site testing instruments are currently available for biological material identification, the field-portable products that could allow soldiers and security personnel to screen for a range of CBE threats are still under development.

Some of the key advantages will be:

- Ability to identify many of the biological, chemical and explosive threat substances.
- High sensitivity (sub parts per billion).
- Non-destructive technique that is not affected by water.
- Little or no sample preparation.
- Compact instruments permit portable and handheld operation.

When portable instruments become available for explosive and chemical agents, this technology could be employed at vehicle inspection sites using sampling protocols that are similar to either small bench top or handheld Ion Mobility Spectrometers.

1.2. Ion Mobility Spectrometry (IMS)

IMS instruments are routinely used at airports and other security checkpoints for screening and detection of explosives, chemical warfare agents, and illicit drugs. They are also used industrially to detect the presence of toxic, contaminating, or volatile chemicals during the manufacturing process for semiconductors, hard disk drives, and other items. Instruments range from small bench top models (such as those seen in the airport) to small battery-powered handheld models. Although many different IMS products are available, they have widely varying capabilities and limitations. Several manufacturers of Ion Mobility Spectrometers that have products directly related to homeland security needs, including Smiths Detection, GE Security, and Particle Measuring Systems, Inc.

Ion Mobility Spectrometers measure the relative migration of gas phase ions through a homogeneous electric field. Solid or gas samples can be analyzed with this system. Sample collection is either by a "sniffing device" for vapors or by a cloth swipe method for particulates. Analysis time is less than 30 seconds, with sensitivities typically reported in parts per billion. Most instruments can detect up to 40 different substances with reliable accuracy, but the instruments need to be recalibrated for each class of compounds before it is used. Each calibration and standardization typically requires about 5 to 10 minutes. Generally speaking, field portable sensors are most effective when used for a dedicated class of threats. For example, if both chemical warfare agents and explosives are tested, it is best to have two separate units that are each calibrated for one threat class.

IMS is the most used technology for detecting explosive and chemical threats. It is fast, reliable, and well tested under many conditions; however, it is not without its limitations. Vapor analysis is temperature dependant. Instruments with vapor sample collection do not function well in environmental conditions outside of their recommended operating range of 65° F. The low vapor pressure of nitroaromatic explosives greatly limits or prevents their detection using vapor collection in cooler environments. Generally, particle analysis gives the best results for using IMS sensors [4]. The analysis is somewhat prone to false positive results. Therefore, calibration standards for a suite of explosive compounds must be run at regular intervals to insure reliable explosive detection results. Similarly, nerve agent detection requires a nerve agent standard run prior sample analysis, and so on. The calibration standards can be purchased from the manufacturer. Single application instruments are generally less expensive than instruments tailored for multiple applications.

All configurations of these instruments are subject to contamination by common substances such as dirt, grease, gasoline vapors and water. In an enclosed vehicle compartment, a person with clothing that is contaminated with grease and oil or other volatiles could likely generate sufficient contamination to register on a portable IMS explosive “sniffer” [4]. Additionally, particle sampling should be collected from clean surfaces. Grease, dirt or water on a swipe can contaminate the inlet of the instrument. Cleaning the inlet at the time of contamination is well within the operator’s control. However, it creates down time (at least 30 minutes) for the instrument. Detection reliability ultimately depends on the user’s careful maintenance and calibration of the instrument. Also, redundant instruments should be available at critical security locations where instrument down time cannot be tolerated.

Typical costs for portable IMS sensors are about $25,000, which does not include the price of consumables needed to keep the units operational. Prices for consumable packages vary with vendor and packaging. First year set up cost of a small bench top model is about $43,000, which includes extended warranty (recommended) and one year of consumable supplies (swipes, inlets, o-rings, etc.). All instruments (field and portable bench top models) are normally maintained by the user and require minimal weekly, monthly, and yearly maintenance. Budget considerations should include consumables and multi-year maintenance to insure long-term use and reliability of the instruments.

Sandia Laboratory has developed a portable IMS unit with a state-of-the-art sample collection. Additionally, they have developed a preconcentration unit for explosive vapor detection that yields impressive sensitivities (parts per trillion). One model combines IMS detection with Lab-On-A-Chip, Gas Chromatography, and Surface Acoustic Wave (SAW) detectors. These detectors use thin film polymer-coated SAW resonators, which are sensitive to specific explosive compounds. Within a year this product should be available [5].

As a whole, IMS sensors have performed very well as explosive and chemical threat sensors and are widely available for this application. They are used with proven reliability and sensitivity in many situations including vehicle inspection points. Given the advancements being made with sampling, portability, user-friendly data analysis software, networks and wireless capabilities, this technology is a good candidate for vehicle inspection points needing threat detection.

1.3. Laser Induced Breakdown Spectroscopy (LIBS)

LIBS is a spectroscopic method that provides elemental identification. Instruments can be purchased that analyze for up to seven different elements at once and also measure their relative abundances. The information collected results in a “finger print” unique to the sample [7].

Some of its benefits include:

- Relatively simple, requiring few if any consumable supplies.
- Analysis time is less than a second.
- Sample size is small (ng), and does not require any preparation.

- Can be used to analyze aerosols remotely.
- Very specific & sensitive (detection can lead to identity).
- Instrument components are small and easily adapted to field application.

The primary disadvantage is that in order to make a positive identification of a substance, its "fingerprint" must be compared to that of a known reference. Therefore, to work effectively the method requires data analysis software packages and access to spectral "fingerprint" data libraries. Also, reference fingerprint data must be acquired under the same instrumental conditions as the sample.

LIBS shows the most promise when applied to the detection and identity of chemical nerve and biological agents. A portable LIBS prototype has been developed that can detect and identify chemical warfare simulants (organophosphate class). Additionally, it can differentiate between different species of mold spores and bacteria found on soil [7]. Its application in IED detection is currently limited to identifying landmines and has been shown to differentiate between plastic and metal landmine casings with about 80% accuracy in controlled field experiments [7].

The direct detection of explosives using LIBS has only been performed under laboratory-controlled conditions [8]. However, the LIBS instrumental components are adaptable to a wide range of applications. Additionally, they give users a significant degree of flexibility, which allows them to physically integrate the components into specialized applications. In the case of vehicle inspection stations, an LIBS system might be useful for a secondary level of inspection for specific hazardous materials (such as nerve agents or biological agent contamination).

1.4. Amplified Fluorescent Polymer Coated Glass Plates

Recent advancements in polymeric coatings have provided a new and powerful tool for CBE sensor development. Although the technology has largely been applied to explosives, it shows equal promise for the future development of sensors that detect chemical and biological agents. The polymer coatings now under development will provide sensors that are both highly selective and sensitive (nominally parts per trillion). They are likely to be used in many of the coating-specific technologies such as fiber optics, SAW and MEMS/microcantilever based detectors [9].

Nomadics recently introduced a portable instrument called FIDO™ that uses a fluorescent polymer based sensor for detection of explosive materials. The FIDO™, sensor makes use of a highly emissive polymer that is only quenched in the presence of an explosive compound. The polymer (which is coated on a glass plate) is chemically designed to amplify this quenching effect and results in an extremely sensitive analysis [10].

Advantages

- Coating highly specific to explosive materials.
- Sensitivity is parts per quadrillion.
- Size: less than 3 lbs.
- Daily startup or reset Startup time: 5 minutes.
- Time between samples: about 5 seconds.

- Per vehicle analysis include sampling: 60 seconds.
- Use and maintenance is relatively simple (user performs maintenance as needed... no company scheduled maintenance).
- Device registered with Safety Act (liability protection for user).

Disadvantages

- Nominal operating temperature is 65° F.
- Vapor sampling is limited by ambient temperature and the vapor pressure of target compounds.
- Particle sampling (using cloth swipes) is most effective when multiple locations such as seats, steering column, and operator's hands are sampled. This is only a disadvantage for high throughput vehicle inspection sites where screening time/vehicle may be constrained.
- Due to the selective nature of the thin coating polymer used in this instrument, the suite of explosive compounds detected is limited.

FIDO™ has many positive attributes for use at vehicle checkpoints where explosive screening is required and it is cost competitive with other small portable explosive sensors currently available [11]. However, the manufacturer declined to respond to questions concerning the durability of the polymer-coated detector. Additionally, they declined to respond to questions concerning the instrument's susceptibility to damage and contamination from conditions encountered during routine sampling.

1.5. Micro-Electro Mechanical Systems (MEMS)

Significant military R&D funding is being directed to the development of MEMS microcantilever sensors. These sensors have received attention as being the next generation of smart sensors that will be used by soldiers and security personnel around the globe. MEMS sensors have just begun to show promising results in many areas of CBRNE threat sensors [12,13,14]. Researchers have demonstrated TNT vapor detection in the laboratory using both coated and uncoated MEMS-based microcantilevers [13]. Microcantilevers can be coated with specially designed polymers that preferentially target the compounds of interest by chemical specificity. Future devices (about the size of a cell phone) will house arrays of coated and uncoated microcantilevers. These devices will be capable of detecting a broad range of CBRNE threat substances [12].

Predicted capabilities include real time analysis that accurately identifies multiple threat substances and will have enhanced sensitivities (sub parts per trillion). Additionally, instruments will have software and wireless capability giving users the capability to access CBRNE data networks.

The Apr-Jun 2007 issue of *Chem_Bio Quarterly* describes a current research effort to develop a SERRS-based instrument with MEMS for chemical and biological agent detection [15]. The sensor(s) will be part of a small portable platform that will have a common network interface. The data collected from these devices will be available to provide usable data feedback and communication via special data networks for anyone that needs remote access to the information. The goals of the current research are ambitious and not without serious challenges.

It is likely that it will be at least a decade or more before these visionary multi-threat sensors will be available.

1.6. Other Technologies

KRD's technical team briefly reviewed a number of sensor technologies and deemed them unsuitable for vehicle inspection systems, at least in the near-term. This determination was based on the relative maturity of the technologies and the lack of validation for threat sensor applications. Some of the following stand-off detection techniques are in use; however, they are not systems that can be practically integrated into an under-vehicle inspection system. These sensor technologies include:

- Gas Chromatography-Surface Acoustic Wave (GC-SAW) analysis for the vapor detection of nitroaromatic and peroxide explosive classes. Nanotherapeutics is currently developing the nanoBREATH ™ product using this technology.
- Field Effect Transistors (FET) and Quartz Crystal Microbalance sensors are a developing technology for CBE applications. However, sensors for explosive detection are not yet available with this technology [16,17].
- Fiberoptic Technology for detection of explosives and other hazardous materials is currently under development by the U.S. Navy.
- Nuclear quadrapole resonance NQR for stand-off detection of explosives.
- Open-path FTIR spectroscopy – for stand-off detection of explosives.
- Differential Adsorption LIDAR – for stand-off explosives [18].
- Quantum Cascade Lasers QCL – for stand-off detection of explosive residue on personnel. It should be noted that equipment is bulky and needs cryogenic cooling [18, 19].

2. Nuclear & Radiological Sensors

The likelihood of encountering nuclear and radiological threats is relative in comparison to improvised explosive devices (IED). However, the consequences of a single nuclear incident are far greater than the average IED. Congress has recognized the possible smuggling of nuclear materials such as weapons, usable uranium, and the radiological waste found in "dirty bombs" as a serious concern at our ports and borders. Therefore, significant funding has gone into sensor and screening systems at high risk locations [20]. The detonation of a "dirty bomb" has not occurred to date, but there have been many reports of suspicious activities involving the building of "dirty bombs" and the smuggling of radioactive wastes by terrorists [21].

Common sensor technologies used to detect radiological and nuclear materials include:

- Personal Pagers – measure radiation exposure levels of individuals wearing them.
- NaI Scintillation Counters – measure gamma radiation.
- Geiger Counters – measure alpha, beta and gamma radiation.

- Neutron Detectors – measure neutrons emitted from fissile materials like uranium.

Sensors used to detect radiological/nuclear threats are presently used in drive-through vehicle inspection points. The NaI scintillation counter is used for screening moving vehicles for anomalous levels of radiation. This instrument is portable, rugged and weather resistant. When combined with small multichannel analyzers it can identify the type of radioactive materials present. Many manufacturers (e.g., ***Amp Tek***) sell portable gamma probes for less than $10,000, which are fully compatible with homeland security applications involving vehicle screening in drive-through checkpoints. ***American Science and Engineering (AS&E)*** and ***Ludlums*** also sell complete drive-through vehicle inspection systems that employ NaI scintillation counters and neutron detectors.

3. X-ray and Gamma Ray Imaging

The sensors described in the previous section can be used to detect the presence nuclear or radiological sources, which are hidden within a vehicle. This is because the radiation from these sources can penetrate through many materials, including metal enclosures of limited thickness.

X-ray and gamma ray sources can also be incorporated into inspection equipment to probe hidden areas within the vehicle and provide images of objects that would not otherwise be visible. Traditional transmission images are obtained by placing the radiation source on one side of the target and the detectors on the other side to measure the transmission of radiation through the target. Backscatter systems, on the other hand, use detectors on the same side of the target to measure the radiation that is reflected back from the target due to the Compton Effect. Backscatter analysis produces detailed images of substances composed of low atomic numbers such as those found in solid or liquid explosives, packets of drugs, and other items. The images allow users to distinguish between organic substances and other substances. Using higher energy sources of radiation can allow imaging through greater metal thicknesses. However, this requires the user to evacuate the passengers of a given vehicle before they inspect it.

Large companies, such as ***American Science and Engineering (AS&E)***, ***Instro Tek ™ Inc***, and ***Ludlums*** offer a broad range of x-ray and gamma ray imaging systems that feature various combinations of capabilities and techniques. In general, x-ray and gamma ray screening allows users to detect suspicious items that could not be found by other means. However, these systems are not a substitute for chemical sensor detection (detecting and identifying explosive vapors is different than imaging an item shaped like an explosive device). X-ray and gamma ray imaging systems are also very costly and require qualified operators trained in image evaluation. It should be noted that this imaging technology does not provide under-vehicle images. Therefore, these systems are complementary to KRD under-vehicle inspection systems.

4. Biological Threat Detection

Biological threat detection implies that the threat is already present (as is also true for chemical warfare agents). Detection of these agents is generally viewed as a way of responding to the threat and reducing further damage/exposure rather than preventing it. Many field portable systems are commercially available for biological agent detection. However, hazardous material response teams who are trained to handle biological and chemical warfare materials primarily use them.

While some bio-threats are well known (such as Anthrax), many biological agents are strictly proprietary. Therefore, techniques for detecting these substances are specific to the agent. Often the microbes must be cultured in specialized laboratories to obtain identity confirmation. Additionally, immunoassay tests can be rendered obsolete if they are not modified as the microbes mutate. Although sometimes used in the field, Polymerase Chain Reaction (PCR) analyses typically require expensive laboratory analysis with significant sample preparation. In general, biological warfare agent screening requires protocols and technology that would be difficult to adapt for effective deployment at routine vehicle inspection check points [1].

5. Sensor Integration Plan

The capabilities and limitations of the CBRNE sensors discussed in the previous sections are summarized in Table 2 and Table 3 of the Appendix. Currently, there is no single platform of sensors or sensory arrays that will detect all forms of chemical, biological, nuclear, radiological, and explosive threats. Although some sensors described in this report are capable of detecting multiple threats, dedicated sensors should be used for each class of CBRNE threats in order to achieve the best results.

In searching for CBRNE sensors for potential integration with KRD's under-vehicle inspection systems we considered the following factors:

- What is the expected selectivity and sensitivity of currently available CBRNE sensors?
- Are sampling techniques available that can deliver a sufficient sample to the sensor for the threat(s) that might be detected at a vehicle inspection checkpoint?
- Are these sampling techniques compatible with the operation of KRD under-vehicle inspection systems? For example, chemical and explosive detection sensors, and x-ray screening procedures require that vehicles be stopped for at least 30 seconds. Therefore, they cannot be used effectively as drive-through screening devices.
- What are the environmental limitations of effective sampling for systems that sample gases and vapors (temperature, humidity, chemical interferences, etc.)?
- What is the total operational cost including the price of the instrument, operation, maintenance, user training, repairs, warranties, and upgrades?

The preliminary findings of this report were presented during a User Evaluation for the KRD vehicle inspection systems in Homer, AK on July 16-17, 2007. At that time, representatives from DoD and AFRL encouraged KRD to solicit input from the end-users on specific requirements for CBRNE sensors before they selected and integrated any of them into their vehicle inspection systems.

In view of these recommendations, coupled with the high cost of relevant sensors, the wide range of possible CBRNE threats, and the current lack of specific threat detection requirements from the end-users, KRD has elected to terminate further research on CBRNE technologies at this time. If specific user requirements for integrating CBRNE sensors with KRD vehicle inspection systems emerge in the future, this report will provide a foundation for further research.

KRD's sensor integration plan, specified as a second year deliverable under the current AFRL contract, has been correspondingly revised to focus on the integration of mass sensors with the KRD under-vehicle inspection system. This will provide a weigh-in-motion measurement in conjunction with under-vehicle inspection procedures to help identify the presence of unusual cargoes that might be hidden from view.

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Appendix

Table 1. Common Chemical Warfare Agents and Explosive Substances

Examples of Common Chemical Warfare Agents	
Choking Agents	Chlorine (Cl) Phosgene (CG) Diphosgene (DG) Chloropicrin (PS)
Nerve Agents ***organophosphorous compounds***	Sarin (GB) **–** Note: liquid @25° F VX **–** Note: liquid @25° F Tabun (GA) Soman (GD)
Blister Agents	Sulfur Mustard (HD) Nitrogen Mustard (HN) Lewisite (L)
Other	Hydrogen Cyanide
Examples of Common Explosives	
Nitro Compounds	High Grade Military TNT – 99% 2,4,6-trinitrotoluene and trace amounts of 2,4-DNT (Nitroaromatic) Picric Acid
Nitrate Esters	Nitroglycerin PETN (penta erythritol tetranitrate)
Nitramines	RDX **(**2,4,6-N-trinitro-1,3,5-triazacyclohexane) HMX **(**1,3,5,7-Tetranitro-1,3,5,7-tetrazacyclooctane)
Salts of Inorganic Acids	Ammonium Nitrate
Organic Peroxides	TATP triacetone-triperoxide
Mixtures	Dynamites Composition B **(**RDX + TNT + desensitizer) ANFO **(**ammonium nitrate + fuel oil) C4 **(**TNT + polyisobutylene + motor oil + diethylhexyl sebacate)

Table 2. Capabilities and Applications of CBRNE Sensor Technologies

Sensor	Detection Threshold	Processing Time	Comments	Applications
Amplified Fluorescent Polymer-Coated Glass Plates	Parts per trillion	1 min	Emerging technology shows promise for a quick and economic screening of CBRE warfare agents.	Biological/Chemical/Explosives/Radiation FIDO™ (Nomadics™) for explosives is currently available for purchase
Ion Mobility Spectrometry IMS	Parts per billion (ammonia) Parts per trillion (explosives❋)	< 1 minute	Currently used in airport security stations for the detection of explosives (TNT and drugs). ❋PPTR sensitivity obtained only by pre-concentration of the sample. Broad uses in industry (clean rooms etc). Can be calibrated to detect many volatile contaminants.	Chemical/Explosives Many portable and benchtop models currently available for purchase
Lab on a Chip with SAW Detection plus IMS	Picogram	1-5 minutes	Combines separation with low sensitivity. Very useful for complex mixtures. Economical, small and portable with low power requirements. Technology/theory very well understood. Its use for CBE analytes really depends on coating development and some uncoated device applications.	Explosives Able to detect Nitro aromatic compounds and Peroxides
LIBS Laser Induced Breakdown Spectroscopy	Nanogram	Immediate	Elemental analysis with a broad band spectrometer Requires a library of spectra to be accurate (i.e., will need significant computer support to access spectra data banks	Biological/Chemical
SERRS/LOC Surface Enhanced Resonance Raman Spectroscopy	Picogram Parts per trillion	2 minutes	Emerging/Imminent technology. Raman Fingerprints for CBE compounds are unique.	Chemical/Explosives/Biological In combination with microfluidic (LOC) technology this will soon be applicable to a broad range of threats.
Neutron/Gamma NaI- Scintillation		Immediate	Ultimate technology for detection of nuclear devices and materials. Able to detect gamma radiation and radioactive waste used for “Dirty Bombs”.	Radiological/Nuclear
X-Ray Transmission and Backscatter Imaging		Scan required	Some systems have color imaging and can discriminate between organics and metallics	Nuclear, Explosive, Chemical devices

Table 3. Cost, Availability, and Operational Requirements for CBRNE Sensors

Sensor Technology	CBRNE Product Availability	Operational/Environmental Limitations	Computing & Network capabilities	Power requirements	Cost
Amplified Fluorescent-Polymer Coated Glass Plates	Yes	Analysis affected by temperature and humidity. Not tested for environmental extremes Recommend temperature is 65° F Array of explosives sensed is limited.	Wireless capability and stores 10 days of data (256 MB memory)	Fully portable (3 lbs) Lithium Battery	\$30,000 (FIDO™)
Ion Mobility Spectrometry IMS	Yes	Vapor sampling is temperature dependant. Particle and vapor samples are affected by environmental contaminants such as oil/dirt and water. Analysis can be susceptible to false positives. Requires frequent calibration.	All portable and bench top units can be adapted for wireless capability. Most instruments come with a software package for data analysis.	Handheld portable units are battery operated.	\$10,000-\$45,000 (Portable / Bench top models)
Lab on a Chip with SAW detection plus IMS	Expected 2008	Polymer coated SAW is affected by pH, humidity and temperature.	Very small and portable with low power requirements.	Handheld portable units are battery operated.	\$40,000 Sandia Hound™
LIBS Laser Induced Breakdown Spectroscopy	NO	Identification of chemical, biological, or explosive agents requires comparison to a spectral library of known compounds. Sample collection technology for CBE agents (vapor and solid) still under development	32- bit, USB compatible Windows PC. Application and correlation software allows for easy operation and immediate material identification	Army prototype is field-portable and can operate for 2 hours on a lithium battery. Commercial units used in the field are fully portable	\$60,000
SERRS/LOC Surface Enhanced Resonance Raman Spectroscopy	NO	Most sensitive techniques require chemical derivitization of explosive compounds.			TBD (\$10-30,000??) Expected to be competitive with other portable system costs
Neutron/Gamma NaI- Scintillation	YES	Vendors must be contacted for information regarding use in temperature/moisture extremes.		Portable and widely used in field.	Nominally \$8,000 - 10,000 /unit
X-Ray Transmission and Backscatter Imaging	YES	Needs a dry protected location for instrumentation (computers, generators and detectors)	System has sophisticated computing capabilities. Special imaging/data analysis software required.	Portable (not handheld). Has specific power requirements (Contact vendors for specs	Very Expensive Contact vendor for detailed price quote